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Microstructure of the Bonding Zone Between AZ91 and AlSi17 Formed by Compound Casting

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Abstract

This paper discusses the joining of AZ91 magnesium alloy with AlSi17 aluminium alloy by compound casting. Molten AZ91 was cast at 650°C onto a solid AlSi17 insert placed in a steel mould under normal atmospheric conditions. Before casting, the mould with the insert inside was heated up to about 370°C. The bonding zone forming between the two alloys as a result of diffusion had a multiphase structure and a thickness of about 200 μm. The microstructure and composition of the bonding zone were analysed using optical microscopy, scanning electron microscopy and energy dispersive X-ray spectroscopy. The results indicate that the bonding zone adjacent to the AlSi17 alloy was composed of an Al_3Mg_2 intermetallic phase with not fully consumed primary Si particles, surrounded by a rim of an Mg_2Si intermetallic phase and fine Mg_2Si particles. The bonding zone near the AZ91 alloy was composed of a eutectic (an $Mg_{17}Al_{12}$ intermetallic phase and a solid solution of Al and Si in Mg). It was also found that the compound casting process slightly affected the AZ91alloy microstructure; a thin layer adjacent to the bonding zone of the alloy was enriched with aluminium.

Keywords: Compound casting process, Joining, Magnesium alloys, Aluminum alloys, Intermetallic phases, Microstructure

1. Introduction

Magnesium and aluminium alloys are widely used in the transport industry because of the great weight saving potential that they offer. Successful research on the joining of Mg with Al as well as the fabrication of Mg-Al compound parts is expected to further increase the application of these materials in lightweight structures. Different methods have been used to join these two types of materials, for instance, MIG welding [1], laser welding [2], friction stir welding [3], diffusion bonding [4,5], hot rolling [6,7], explosive cladding [8], twin-roll casting [9].

The literature data show that compound casting is successfully used to join different metals or alloys to produce bimetallic castings such as steel/cast iron [10-12], steel/cast steel [13], steel/silumin [14,15] and Cu/Al [16]. This method seems to be the economic and promising to produce lightweight Mg-Al parts. In this process, a metal alloy in the liquid state is cast directly onto a solid metal alloy substrate. The literature concerning this method has discussed the joining of commercially pure Mg to AlMg1 aluminum alloy [17], pure Mg to pure Al [18-21]. A continuous transition bonding zone forms between Mg and Al as a result of diffusion processes occurring at the reactive interface. The bonding zone is mainly composed of Mg-Al intermetallic phases and has much higher hardness than both Al and Mg metals. Due to formation hard and brittle intermetallic phases the Mg/Al joints are characterized by relatively low strength. The results of a literature search indicate that no attempt has been made to use compound casting to join cast Mg-based alloys to cast Al-based alloys. It is thus justified to study the use of this method to join AZ91D alloy to hypereutectic silumin.

In this work, the method of compound casting was applied to connect AZ91 magnesium alloy with AlSi17 aluminum alloy. The paper focuses on the microstructural analysis of the bonding zone.

2. Experiment

AZ91D magnesium alloy with a chemical composition of Mg–9.14Al–0.64Zn-0.23Mn (wt%) was used as the cast material. AlSi17 cylindrical inserts 30 mm in diameter and 5 mm in thickness were cut from an ingot. The AlSi17 studied was composed of 17.18% Si, 1.22% Mg, 0.82% Ni, 0.72% Cu, 0.25% Fe and 0.02% Zn with a balance of Al. The surface was ground with silicon carbide papers up to 800 grit. Then, an insert was placed at the bottom of a steel mould. The mould with an insert inside was heated up to about 370^{o}C. The AZ91 was melted under pure argon atmosphere. The casting process involved pouring 100 grams of molten AZ91 at 650^{o}C onto the AlSi17 insert placed in the mould cavity under normal atmospheric conditions. When the temperature of the mould and the insert inside was lower, i.e. less than 300^{o}C, a continuous bonding zone did not form between the alloys.

The microstructure of the bonding zone formed during the compound casting process was determined by means of a Nikon ECLIPSE MA 200 optical microscope and a JEOL JSM-5400 scanning electron microscope. The specimen preparation for the microscopic observation did not involve etching; the final polishing was performed using a colloidal silica suspension. The phase composition was analysed using an Oxford Instruments ISIS 300 X-ray energy dispersive spectrometer (EDS) attached to the SEM. The phases were identified through an EDS analysis on the basis of phase diagrams for Mg-Al [22] and Al-Mg-Si [23]. The results of the EDS quantitative analysis provided here are the arithmetic mean of the results from several (generally three) measurements.

3. Results and discussion

As shown in Fig. 1, the joint between the two materials was produced by pouring molten AZ91 onto an AlSi17 insert. The bonding zone with a multiphase structure had a thickness of about 200 μm. The resultant bonding zone between AZ91 and AlSi17 was continuous and had a uniform thickness across the entire cross-section.

Figure 2 shows an SEM image of the interface between the AlSi17 and the bonding zone. Large primary Si particles are visible both in the AlSi17 alloy and in the bonding zone, but in the bonding zone the particles are surrounded by a dark phase. Furthermore, in the bonding zone, fine dark phase particles are observed in the grey phase matrix. The chemical composition of the grey phase matrix (results of the quantitative analysis at point 1: 59.6 at.% Al, 39.74 at.% Mg and 0.66 at.% Si) near the AlSi17 alloy suggests an Mg_2Al_3 intermetallic phase. The EDS results at point 2 in the AlSi17 alloy matrix (97.22 at.% Al and 2.78 at.% Si) indicate a solid solution of Si in Al.

Figure 3 presents details of the microstructure of the bonding zone near the AlSi17 alloy and the corresponding EDS line scan results showing the concentration profiles of the elements (Mg, Al and Si). The results of the EDS quantitative analysis for the dark area (analysis at point 1: 64.54 at.% Mg, 33.44 at.% Si and 2.02 at.% Al) and the dark particles (analysis at point 2: 63.52 at.% Mg, 34.3 at.% Si and 2.18 at.% Al) suggest the presence of an Mg_2Si intermetallic phase. This indicates that the decomposition of the Si grain was a result of the diffusion process. The primary Si particles and the eutectic Si particles present in the AlSi17 alloy reacted with the Mg, which led to the formation of an Mg_2Si intermetallic phase in the bonding zone. The results provided in [24] show that the heating of the AlSi20/Mg couple at 430^{o}C caused the formation of a transition layer at the AlSi20/Mg interface containing an Mg_2Si phase, which is a product of the reaction between the Mg and the primary Si grains. Asano and Yoneda [25] also confirm the in situ formation of Mg_2Si particles in the surface layer of the AZ91D as a result of casting magnesium alloy melt into a mould coated with a slurry containing Si particles. The chemical composition of the grey phase area (analysis at point 3: 58.88 at.% Al, 40.52 at.% Mg and 0.6 at.% Si) is similar to that of the Mg_2Al_3 intermetallic phase, which confirms the above findings that the grey matrix in the bonding zone near the AlSi17 is this phase.

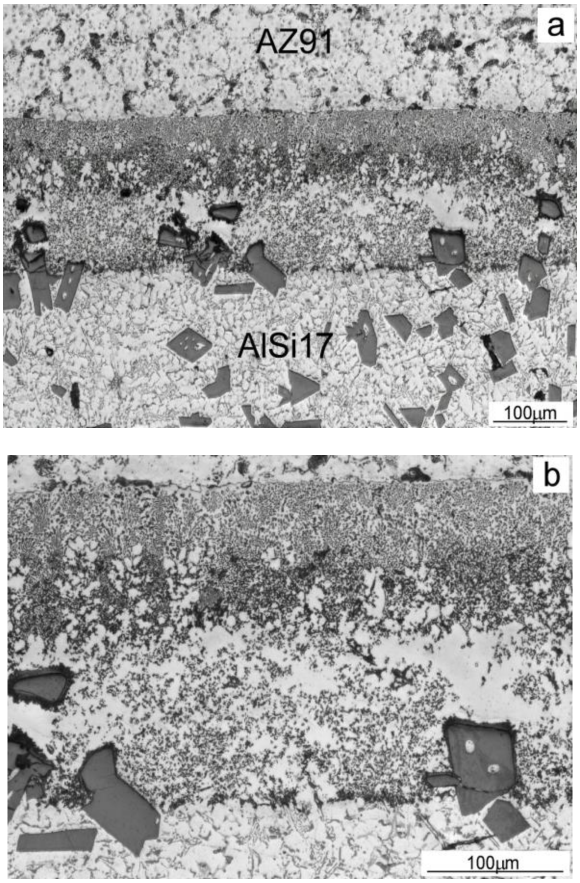

Fig. 1. OM images of the microstructure of the bonding zone formed between AZ91 and AlSi17 by compound casting: (a) lower magnification, (b) higher magnification

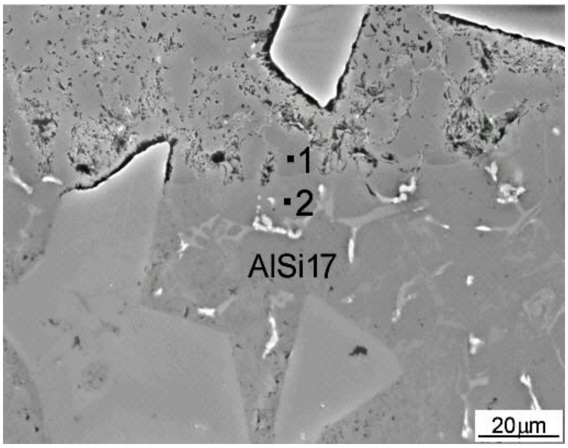

Fig. 2. SEM image of the interface between the AlSi17 and the bonding zone.

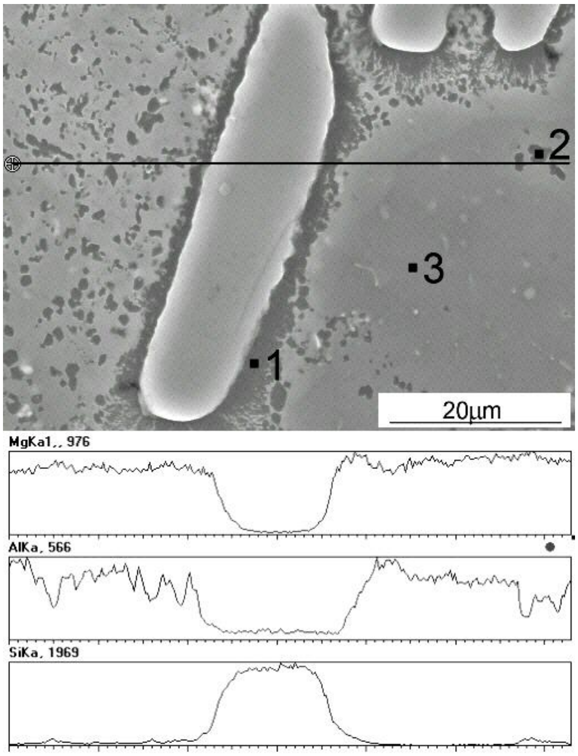

Fig. 3. Microstructure of the bonding zone adjacent to the AlSi17 with a distribution of elements (Mg, Al and Si) along the marked line

Figure 4 shows the microstructure of the bonding zone on the AZ91 alloy side. Near the AZ91 substrate, there is a two-phase eutectic composed of light and dark phases (marked 1 and 2, respectively). The results of the EDS quantitative analysis conducted for the light phase (63.85 at.% Mg and 36.15 at.% Al) indicate the occurrence of an $Mg_{17}Al_{12}$ intermetallic phase; those reported for the dark phase (84.53 at.% Mg, 14.98 at.% Al and 0.58 at.% Si) suggest a solid solution of Al and Si in Mg. The eutectic is thus composed of $Mg_{17}Al_{12}$ and a solid solution of Al and Si in Mg. As shown in [18-21], the bonding zone in the Mg/Al couples fabricated by compound casting in the vicinity of Mg was also composed of the eutectic ($Mg_{17}Al_{12}$ and a solid solution of Al in Mg). The microstructure and phase composition of the bonding zone change gradually with increasing distance from the AZ91 alloy. The phases present in the zone become poorer in Mg and richer in Al and the Mg_2Si phase occurs. The composition of the large light phase area near the eutectic zone (analysis at point 3:63.06 at.% Mg, 36.61 at.% Al and 0.33 at.% Si) also indicates the $Mg_{17}Al_{12}$ phase. However, when the analysis was conducted in the single-phase area at a certain distance from the eutectic (analysis at point 4: 42.59 at.% Mg, 55.03 at.% Al and 2.38 at.% Si), the composition of this area was more similar to that of the Al_3Mg_2 intermetallic phase. The fine dark particles of the Mg_2Si phase were observed above the eutectic zone (see Fig. 4).

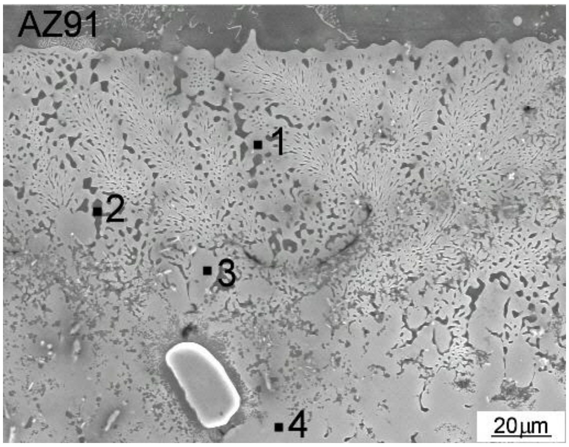

Fig. 4. SEM image of the interface between the AZ91 and the bonding zone.

The microstructure of the AZ91 alloy after the compound casting process was analysed at a distance of 500 μm from the bonding zone (Fig. 5) and near the bonding zone (Fig. 6). The comparison of the two images indicates that the microstructure of the AZ91 alloy close to the bonding zone changes significantly. The microstructure presented in Fig. 5 is typical of cast AZ91 magnesium alloy, which is composed of an α-Mg matrix and irregularly distributed precipitates of the $Mg_{17}Al_{12}$ phase along the grain boundaries. The amount of the $Mg_{17}Al_{12}$ phase near the bonding zone is larger. This finding indicates that the thin layer of the AZ91 alloy adjacent to the bonding zone was enriched with aluminum during compound casting.

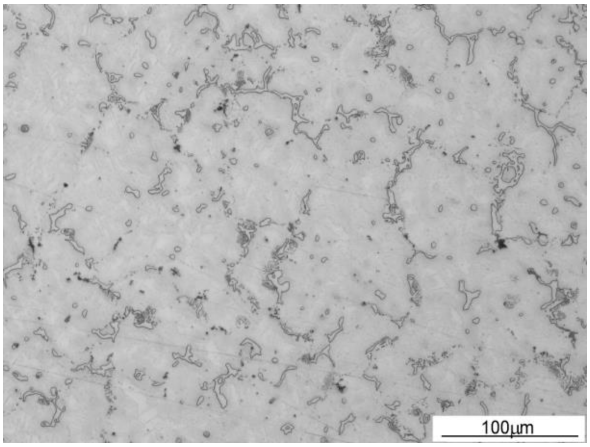

Fig. 5. Microstructure of AZ91 alloy observed at a distance of 500 μm from the bonding zone

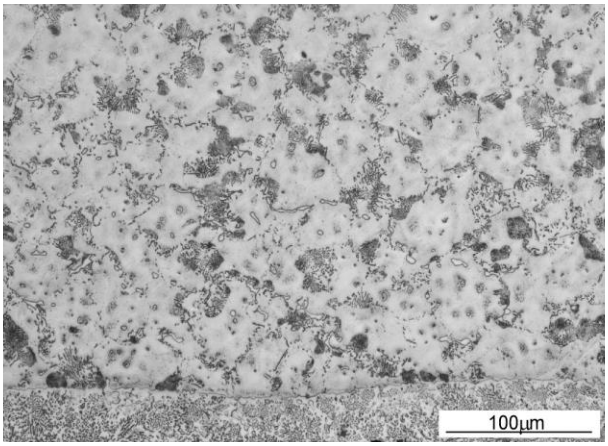

Fig. 6. Microstructure of the AZ91 near the bonding zone

4. Conclusions

The results have shown that it is possible to join AZ91 magnesium alloy to aluminium AlSi17 alloy using the compound casting process. The bonding zone with a thickness of 200 μm was formed at the AZ91/AlSi17 interface after casting molten AZ91 onto a solid AlSi17 insert. The bonding zone on the AlSi17 side contained Si primary particles surrounded by a rim of an Mg_2Si intermetallic phase and fine Mg_2Si particles on the Al_3Mg_2 intermetallic phase matrix. The microstructure of the bonding zone on the AZ91 side was characterised by a eutectic composed of an $Mg_{17}Al_{12}$ intermetallic phase and a solid solution of Al and Si in Mg. The microstructure of the AZ91 magnesium alloy near the bonding zone changed; the thin layer of the AZ91 adjacent to the bonding zone was enriched with aluminium.

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